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AND
APPLICATION TO SWITCHING DEVICES

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Avalanche Breakdown Mechanisms and Application to Switching Devices

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Introduction:

The purpose of this report is threefold. 1) to present a discussion of avalanche breakdown which is the primary high voltage limiting mechanism in semiconductor junction devices. 2) to discuss surface field effects on avalanche breakdown and junction termination techniques for reducing these surface effects. 3) to present a discussion of avalanche second breakdown and its application to high voltage, high speed, switching devices. One of the goals of these discussions is to present the current state-of-the-art in the area of junction breakdown and high voltage junction devices. Since only a cursory description of the subjects can be given in this short report, a large list of references is compiled to help the reader pursue these areas further.

Avalanche Breakdown:

Junction breakdown in high voltage semiconductor devices is almost always determined by the avalanche breakdown process. Avalanche breakdown occurs when a carrier moving in the reverse bias electric field of the depletion layer can gain sufficient energy to knock another carrier out of the conduction or valence band during a collision. This process is strongly dependent on the electric field in the depletion layer. The probability of breakdown for a given electric field distribution is calculated by the ionization integrals which integrate the ionization coefficients across the depletion layer [1-2]. Fig. 1 shows the ionization coefficients for electrons and holes as functions of electric field and temperature. The curves for the higher temperatures are extrapolated from the lower temperature data and may not be entirely accurate. Because of the strong electric field dependence of breakdown, all techniques for increasing breakdown voltage involve the reduction of electric field in the depletion layer. In the one dimension into the bulk the task is relatively simple very high breakdown voltage can theoretically be achieved by simply making the p and n regions lightly doped and very wide. The real limiting effects are the two and three dimensional electric field effects at the edge of the semiconductor device where the junction comes to the surface.

Surface Breakdown:

Surface breakdown, as referred to here, is the effect of a reduced p-n junction breakdown because of a higher electric field across the junction at the surface of a semiconductor device [3]. The causes of this increased surface electric field are many, including dangling bonds at the surface of the semiconductor material, differences in dielectric constant between the semiconductor and the material surrounding it, fixed charge in the material coating the semiconductor surface, and curvature of diffused junctions. A variety of techniques have been suggested to reduce the surface electric field and thereby increase breakdown voltage [4]. These include beveling and etching the surface to change the charge distribution near the junction edge [5-9], field limiting diffusions [10], and field plates covering the junction edge [11-13]. Among these reports, the highest breakdown voltage was 10 KV, achieved using a semi-insulating polysilicon (SIPOS) field plate [13].

Second Breakdown and Switching:

If the current through a device is allowed to increase after breakdown is reached, a second breakdown is seen wherein the voltage across the device collapses to a much lower value as shown in Fig. 2. This negative resistance region of the characteristic is very useful for very high speed switching. A switching device called the "Avalanche Transistor" is based on this phenomenon [14]. Switches capable of holding off up to 1000 V and conducting several 10s of amps of current have been made with switching times of less then 5 nanoseconds [15]. This second breakdown phenomenon is not very well understood. Recently, two distinct regimes of second breakdown were described [16], one called thermal mode is relatively slow (microseconds), the other called current mode is fast (nanoseconds). One explanation of second breakdown is that it is a feed back effect in which carriers generated by avalanche multiplication forward bias the emitter base junction of bipolar transistors [17]. The discovery of a similar second breakdown in diodes tends to shed some doubt on this theory [18-19]. In fact the switching speed in diodes is substantially faster than in transistors. Fig. 3 is a pulse generated, by a circuit using one of these diodes, in our laboratory having a peak amplitude of 2800 volts (56 Amps.) and a rise time of less than 0.5 ns. These devices are extremely useful for generation of high voltage pulses where low jitter and electrical triggering are a requirement.

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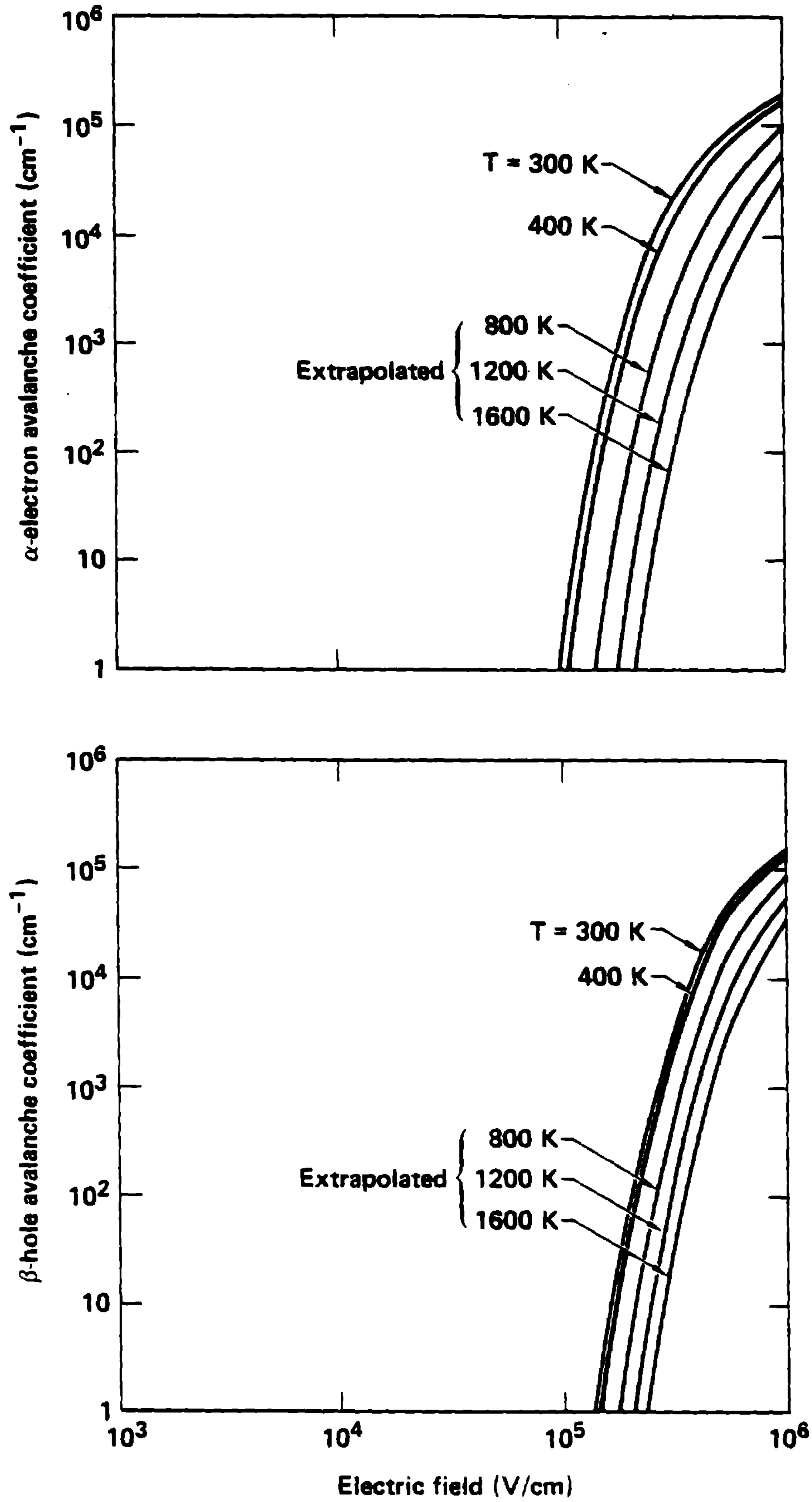

Figure 1. Ionization coefficients verses electric field for several temperatures.

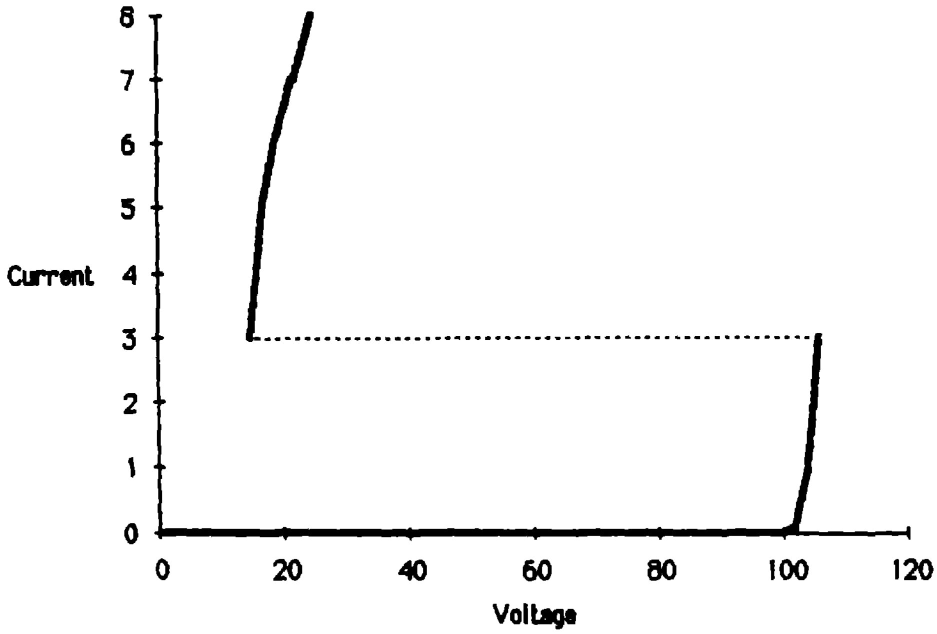

Figure 2. Current/voltage characteristics illustrating second breakdown in a junction semiconductor device

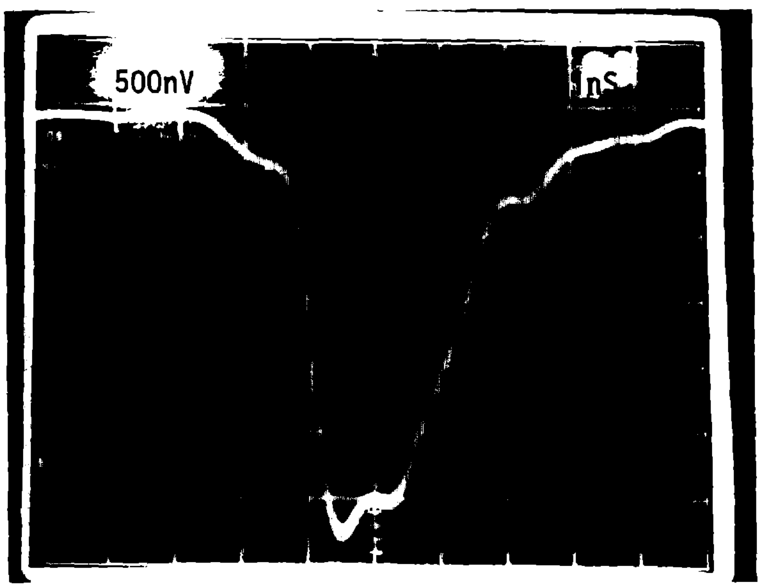

Figure 3. A 2800 volt 300 picosecond rise time pulse generated using the fast second breakdown effect in a silicon diode.